Rim Fire: Vegetation Resiliency Project
For the Stanislaus National Forest

November 2013

Authors: Shelly Crook, Carol Ewell, Rebecca Johnson, Scott Cones, Becky Estes, Ben Newburn, Lynn Goolsby, Steve Baran, and Alec Lane

Contributors: Neil Sugihara, Phil Bowden, Maria Benech, Carly Gibson, and analysis by Joe Scott

Figure 1. Representative plantation conditions in 2012 across the Stanislaus Complex restoration and Wrights Creek areas on the Mi-Wok Ranger District. Shrubs and small tree patches often burn at high intensity and create high severity effects.

Purpose of this Report

After the Rim Fire the Stanislaus National Forest (STF) is utilizing this opportunity to design and describe the desired fire management and fuel treatment goals within the burned area. This report is designed to serve this landscape into the future and enhance forest sustainability for the next 100 years. This report describes a foundation-type framework for fire and fuel management activities, consistent with the STF Forest Plan and the Sierra Nevada Forest Plan Amendment (SNFPA), to guide upcoming fuel removal, reforestation, and other post-Rim Fire ecosystem restoration activities on the landscape scale. This report will need to be updated as new science and planning documents are developed and planning area needs are considered within an interdisciplinary context. This strategy is focused on working toward desired conditions that are 1) resilient to the predictable occurrence of future fires, 2) provides sustainable habitat for native biotic communities and species, 3) minimizes the potential for large scale impacts to local communities, watersheds, and ecosystems by restoring a more natural mosaic of fire occurrence and 4) is implementable given the limited resources available to the Forest.

Background

Wildfire is a natural process, which helps to promote ecosystem resilience in Sierra Nevada forests. Fire was once very common throughout the Sierra Nevada and provided a primary force for shaping the structure, composition, and function of ecosystems native to these mountains. Future management strategies need to recognize, in many situations, fire is both a viable fuel-treatment tool (Agee and Skinner 2005, Stephens and others 2009) and an important 'jumpstart' for many ecosystem processes stalled by accumulating surface fuels and the absence of frequent burning (North 2006).

Studies in the Sierra Nevada indicate mixed conifer forests were highly clustered and less continuous than observed at present, with groups of trees separated by sparsely treed or open gap conditions (North and others 2009, Lyderson and others 2013). A recent study of drought stressed Jeffrey pine/mixed-conifer forests found spatial age-class and ecosystem heterogeneity was a key feature of forest resiliency (Stephens and others 2008). These forests experienced frequent fire and generally consisted of widely spaced, large trees, most of which were pines; however areas of higher density forest communities also existed on moderate slopes, valley bottoms, and northern aspects. Fuel treatments that produce uniform leave tree spacing *reduce* this ecologically important spatial heterogeneity by creating uniform ecosystem structure within the landscape. Sierran forest structure reconstruction studies suggest mixed-conifer forests under an active fire regime had a naturally clumped distribution containing a variety of age and size classes (Barbour and others 2002, Bonnicksen and Stone 1982, Minnich and others 1995, North and others 2007, Taylor 2004). In addition, recent findings in Yosemite National Park show that low to moderate severity fires create these mosaics of tree clumps and openings (Kane and others 2013). This report focuses on the mixed-conifer ecosystems that made up the majority of the burned area. Some of these concepts presented are can be readily extrapolated to other vegetation types found within the Rim Fire.

Fire return intervals and departure from those intervals are well documented for large sections of the Sierra Nevada Range (Safford and others 2011) and focus on temporal frequency of fire for given vegetation types. A natural fire return interval is a general classification of the role fire would play across a landscape over time in the absence of modern human mechanical intervention, and estimating the influence of aboriginal burning (Agee 1993, Brown and Smith 2000, Interagency FRCC Guidebook 2010 [Barret and others 2010]). Fire regimes are characterized by the frequency, duration, magnitude, and severity of fire and can be used to infer the pre-settlement fire regime before Euro-American settlement. Fire Return Interval Departure (FRID) is calculated by dividing the number of years in the fire record by the number of fires occurring between 1908 and the current year plus one (Safford and others 2011). Figure 2 illustrates the mean FRID condition class for the area before the Rim Fire, providing spatial context of contemporary fire (i.e. since 1908) frequency based on known pre-settlement fire history. The mean reference FRI was the basis for comparison.

The need for fuel treatments to manage potential fire behavior is widely recognized, but the financial commitment to re-treating these areas to mimic natural fire return intervals is often non-existent. In fact, North and others (2012) concluded that less than 20 percent of the landscape is being actively treated for fuels in the Sierra Nevada landscape is receiving needed fuel treatments, so this scale and pattern, along with the need to frequently re-treat many areas, has amounted to limited success of restoration goals associated with these treatments. The authors suggest that after fuels reduction projects are completed, these areas should be transitioned into a cycle of fire maintenance, rather than managing for fire suppression. They recognize that this needs to be done at a landscape level across entire watersheds, requiring a shift in current management focus.

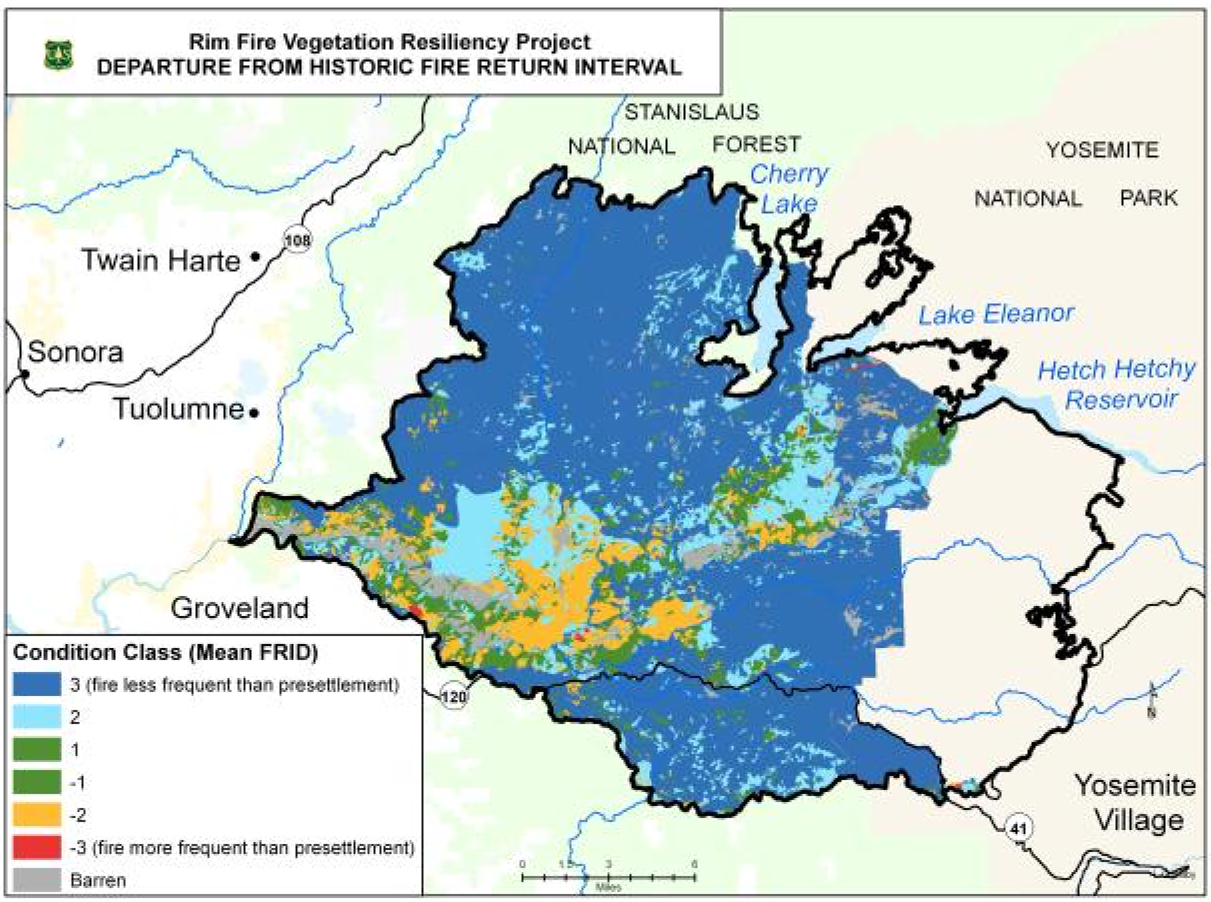

Figure 2. Mean Fire Return Interval Departure (FRID) Condition Class.

PSW-GTR-220 (North and others 2009) can be used as a guiding document for ecosystem management for Sierran mixed-conifer forests and within the Rim Fire area to promote vegetation resiliency. The risks of carefully considered active forest management are lower than the risks of inaction and continued fire suppression in the Sierras' fire-prone forest types (Collins and others 2013). Large, uncharacteristically severe fires affect ecosystem services on a landscape scale and have great potential decreased age and ecosystem heterogeneity in the long-term.

Current Sierra Nevada forest management is often focused on strategically reducing fuels without an explicit strategy for ecological restoration across the landscape matrix. Summarizing recent scientific literature, PSW-GTR-220 suggests managers produce different stand structures and densities across landscapes using topographic variables (e.g., slope shape, aspect, and slope position) as a guide for varying treatments. Collectively, management recommendations emphasize the ecological role of fire, changing climate conditions, sensitive wildlife habitat, and the importance of forest age and structural heterogeneity. PSW-GTR-220 offers alternatives to manage for different structural and fuel conditions while retaining extant habitat structures (e.g., hardwoods, large snags, groups of large trees). *Post-fire landscapes offer an opportunity to develop long-term strategies that can realign ecosystem structure, function and composition so that they will be resilient under the present fire regimes and the future changing climate.*

Designing treatments to increase landscape heterogeneity

Site conditions will often determine what size tree groups and gaps or openings can be shaped to improve landscape ecosystem heterogeneity, which leads to increased resilience. Tree groups also occur at larger extents, such that several small-scale clusters are nested within a larger group. However, if a contiguous group of trees occupies too large an area, forest conditions can add to potential fire intensity. Forest gaps impede fire spread (Agee and Skinner 2005) and therefore may reduce fire severity in forests where adjacent areas of high canopy cover are retained. Stand structure reconstructions in mixed-conifer/giant sequoia ecosystems suggest a wide range of gap sizes with most gaps less than 0.5 acres (Piirto and Rogers 2002, Lyderson and others 2013). Locating gaps in areas with thinner soils or lower productivity may be logical to foster lower canopy cover since these areas historically supported lower tree densities and fuel loads (Meyer and others 2007). The relative proportion of these landscape conditions (i.e., low density, dispersed large trees, and large and small gaps and tree groups) and their composition could be varied depending on existing forest conditions and topographic position.

Some principles outlined in PSW-GTR-220 can be applied to stand-level conifer plantations, especially the when planning to increase spatial heterogeneity. The high uniformity of plantations (both spatially and temporally) makes them vulnerable to catastrophic change from fire, insects, and disease; single-species plantations are the most vulnerable and contribute to these events. Thinned plantations can experience high mortality in most wildfire conditions (Stephens and Moghaddas 2005, Kobziar and others 2009). Modifying plantation tree density will not reduce the probability of mortality unless surface fuel loads are reduced and height to the base of the live crown is increased. Once a plantation reaches the stem-exclusion phase (Oliver and Larson 1996), silvicultural activities that produce gaps, increase the height to live crown (e.g., pruning, mastication, prescribed fire), and reduce surface fuels will increase plantation resiliency and persistence when exposed to fire. Recent research has also shown that prescribed fire treatments either before or following plantation establishment can increase the likelihood of survival following a fire (Kobziar and others 2009). Marking guidelines based on leaf area index may offer greater flexibility for designing silvicultural prescriptions grounded in more direct measures of physiological and ecological processes. For thinning, marking rules would be based on crown strata or age cohorts and species, rather than uniform diameter limits or tree spacing. Heterogeneity and resilience can also be fostered by planting seed stock that would respond well under unknown future climates, planting fire-resistant tree species, planting at variable tree densities (i.e., planting in groups, single trees and leaving openings), and aligning plantations to reintroduce fire as a tool (Long and others 2013). Reduction is needed in both canopy and understory fuels to reduce subsequent fire severity.

As climate changes, managing fire behavior may produce more resistant and resilient forests, compared to managing for a desired number, size and spacing of trees. Managing forests during influences of climate change such as longer fire seasons and changing temperature and precipitation patterns can result in uncertainty. Millar and others (2007) have suggested managers consider adaptive strategies focused on three responses: *resistance* to forestall impacts and protect highly valued resources; *resilience* to improve the capacity of ecosystems to return to desired conditions after disturbance; and *response* to facilitate transition of ecosystems from current to new conditions. These ecological concepts and strategies acknowledge the influence of climate change and suggest management may fail if focused on re-creating past stand conditions using strict structural targets.

Fire is an indispensable management tool, capable of doing much of the work to restore ecological processes (Bond and van Wilgen 1996, Covington and others 1997, North 2006, Stephenson 1999, Sugihara and others 2006). In many stands, mechanical thinning followed by prescribed fire may be necessary to achieve forest resilience much faster than with prescribed fire alone (Schwilk and others 2009, Stephens and others 2009). Surface fuels merit as much attention as ladder fuels when stands are treated. Prescribed fire is generally the most effective tool for reducing surface fuels.

RMRS-GTR-310 (Reynolds and others 2013) also presents a management framework for improving the resistance and resiliency of frequent-fire forest ecosystems to severe disturbances. The key compositional and structural elements of this restoration framework are: (1) species composition that recognizes both tree and understory vegetation; (2) groups of trees; (3) scattered individual trees; (4) open grass-forb-shrub interspaces/gaps between tree groups and individual trees; (5) snags, logs, and woody debris; and (6) variation in arrangements of these elements in space and time. Where forest composition and structure allow, RMRS-GTR-310 recommends that fire, the primary historical disturbance agent in these forests, play a prominent role in their restoration. This framework also emphasizes that mechanical treatments may be necessary to initiate suitable composition and structure before reintroducing fire. Where use of fire is limited, mechanical treatments may be the only available tool to create and maintain restored forests. Conversely, fire may be the only tool in some areas. Implementation of the PSW-GTR-220, RMRS-GTR-310, and PSW-GTR-237 (North 2012) concepts should improve overall ecosystem productivity and function and enhance ecosystem constituents to increase landscape heterogeneity; this report draws from these frameworks.

Background Summary points

1) Existing research shows that mixed-conifer forests were heterogeneous in space and time and low to moderate fire severity was the primary driver of this landscape condition.
2) The importance of introducing small scale, low-intensity, and high-frequency fire to reduce the vulnerability of large scale events is a key component to maintaining ecological resilience. For example, managing wildfires within large control features and under a range of weather conditions can be conducive to meeting restoration objectives.
3) Topography is very important when evaluating fire severity patterns. Reforestation efforts should focus on areas with topographic characteristics likely to experience low to moderate severity fire. It is also important to consider these trends when evaluating tree density and structure.

4) Recognize that certain areas may sustain trees in the absence of fire, but if a potential natural vegetation system was considered with active fire processes, many areas would not be capable of maintaining high tree densities.
5) Fuel treatments are designed to moderate the intensity and severity of potential fires. Treatment maintenance is essential to their effectiveness, and overall landscape resilience often increases with maintenance of each treatment unit.

Current Conditions

On the Stanislaus wildfire is the most significant vegetation/fuels treatment mechanism. STF has not implemented prescribed fire or mechanical treatments on the scale necessary to restore landscapes. Therefore, STF's primary method, based on a multi-decade perspective, is wildfires followed at smaller scales by prescribed fire, pile burning, timber harvest, and mechanical or hand thinning (including mastication). Wildfires can be utilized both as primary fuel treatments and as follow up maintenance treatments.

Forest resiliency and associated vegetation matrix are landscape scale concepts that are difficult to sufficiently address within a fire perimeter, even one as large as the Rim Fire. Planning within just the Rim Fire area and not the rest of the connected landscape is problematic because the process of ecosystem restoration and fire or vegetation resiliency is larger than the Rim Fire. Planning at this large scale would be better addressed by a Forest-wide analysis and in conjunction with connected landowners. Examples are the CFLRA Program, such as Cornerstone and the Yosemite Stanislaus Solutions; the Southern Sierra Wildfire Risk Assessment; and use of the Fire Program Analysis (FPA) application.

The PSW Science Synthesis (Long and others 2013) has recommendations for post-wildfire management. Post-fire treatments target sites where the expected benefits exceed the costs of interventions and addresses scrutiny about cost effectiveness and undesirable ecological effects. These interventions are likely to occur in areas of high severity that are larger than the range of expected variation. Increasingly, recently burned areas are reburned (e.g., 2012 Chips Fire reburned part of the 2000 Storie Fire, 2013 Rim Fire reburned the 1999 Pilot Fire [Figure 7], the 2013 Corral Complex reburned parts of the 1999 Big Bar Complex [Figure 3]) and present valuable opportunities to understand long-term socio-ecological resilience. Research suggests that substantial social support exists for salvage logging in fire-prone communities because this post-fire action has a number of benefits, such as increased aesthetic beauty, increased safety for recreational forest users, avoidance of waste, reduced fire risk, and economic benefits (McCaffrey 2008, Ryan and Hamin 2006, 2008, 2009). Research is needed to resolve the many questions that remain concerning the short- and long-term effects of salvage logging. Post-fire landscapes offer opportunities to realign ecosystem structure, function, and/or composition with expected future climate and fire regimes.

Figure 3. Firefighters (middle of photo) installing control lines for the 2013 Corral Complex reburning the 1999 Big Bar Complex illustrating the complexity of hazardous snags and thick shrub regrowth.

The PSW Science Synthesis partially addresses shrubland and hardwood communities, and acknowledges further research needs. Severe fires may induce a reversion from forests back to shrubfields that were present under an earlier fire regime (Beaty and Taylor 2008, Nagel and Taylor 2005), and may be important for promoting or maintaining chaparral communities on upper and south-facing slopes, and for restoring structural heterogeneity to the landscape (Crotteau and others 2013, Nagel and Taylor 2005). Likewise, high-severity fire may be a critical process in the restoration of heavily encroached black oak stands. High and moderate severity fire may induce oaks to resprout, giving them a competitive edge over encroaching conifers (Cocking and others 2012). However, uncharacteristically severe fire may also induce type conversions that may not have occurred had the forested areas already been in a more fire resilient condition (Skinner and Taylor 2006). Refraining from active treatment may be appropriate in areas where the ecological trajectory of a post-fire landscape seems to align with desired conditions, which may include regeneration of hardwoods, chaparral, or other shrubs (Taylor 2004). In areas where particular resource values are highly threatened, active restoration may be warranted to guide succession toward desired conditions. Habitat connectivity could be fostered by designing treatments to maintain desired habitat patches and corridors within or surrounding the fire perimeter. Monitoring post-fire landscapes can help managers determine the likely trajectory of ecosystem recovery in the post-fire environment, prioritize areas for treatment, evaluate when important thresholds might be crossed, and address specific research gaps (e.g., habitat needs of species associated with post-fire conditions, climate change leading to large-scale failures for trees to regenerate). Further research is needed to understand effects of wildfires, and high-severity patches in particular, over long periods and after multiple fires, including effects on fuelbeds, ecological trajectories, wildlife species associated with post-fire conditions and old forests, streams, watersheds, economic values, and social well-being. Sugihara and others (2006) also have a wealth of information about fire in California's bioregions, including which shrubs and hardwoods have sprouting and seeding responses that are fire stimulated.

Fire ecology of specific flora and vegetation communities are readily available on the Fire Effects Information System (FEIS) (USFS 2013), which also serves as a location for science synthesis. Treatment prioritization concepts in shrubland and oak-hardwood communities are not well outlined in the above mentioned frameworks. Much of the pre-Rim Fire landscape had a reduced extent of many oak woodlands from natural encroachment by conifers or from conifer-based plantations. FEIS provides users with fire regimes and burn severities that favor different vegetation communities, which also describes target natural processes for continuing and developing landscape heterogeneity that includes shrublands and oak-hardwoods.

The following information is from FEIS. Historic fire regimes in oak forests and woodlands were characterized by relatively frequent, low- to moderate-severity surface fires with short- to medium-length fire-return intervals (around 8 to 10 years), which favored neighboring ponderosa and sugar pines, oaks, and sprouting shrubs over shade-tolerant, fire-sensitive species such as incense-cedar and white fir. Patchy stand-replacement fire was important in maintaining California black oak stands. Pioneer accounts of persistent California black oak and chaparral stands, which are generally maintained by stand-replacement fire, within ponderosa pine and mixed-conifer forests suggest that patchy, stand-replacement fire occurred occasionally in low- and mid-elevation forests. Patchy, severe fire may have helped maintain California black oak stands within conifer forests. Without very frequent fire (less than 10 years), California black oak cannot maintain dominance on most sites and is successionally replaced by conifers. Chamise has adaptations that enhance its flammability and result in intense, fast-spreading, potentially large fires which have an increased probability of occurring as a stand matures. Chamise chaparral produces fuel loadings capable of supporting a moderately intense fire within approximately 15 years, and chamise rapidly reoccupies the post-fire community.

Primary Fire Management Treatment Objectives within the Rim Fire Perimeter

Strategic fire management *features* were identified along roads and ridgelines to take advantage of natural or topographic features and established roadways. Features were also located adjacent to private property, and connected through private Sierra Pacific Industries (SPI) managed land. In addition to fire behavior modification, features create safe travel route options for emergency access/egress.

Strategic fire management *areas* were identified along many features to reinforce and transition the vegetation density across the areas. These would also create locations for safer management actions as well. These *areas* can serve as strategically placed landscape treatments (SPLATs) to break up the continuity of the vegetation across the landscape, create mosaic patterns, and provide a network of opportunities for wildfire management objectives that allow for equal weight of natural resource and ecosystem benefits and protection of private property.

A map of optimum locations for fuels treatments and fire management objectives was developed (Figure 4). District Fire and Fuels managers identified their ideal priority treatment features (i.e., fuelbreaks) and areas (i.e., polygons or SPLATs). Treatment locations were based on the combination of professional judgment, onsite knowledge, job skills, experience with the Rim Fire, recent and other past wildfires, and District NEPA analysis, and treatment history. The following photos were included to illustrate desired conditions of open canopy and understory fuel conditions in three vegetation categories (Figures 5-7).

Strategic Fire Management *Features*

Description: linear treatments or fuelbreaks (as compared to polygons) based on existing fuelbreaks, topographic features like ridgelines, and existing or unmanaged/decommissioned roads, of variable width as determined by potential fire behavior.

Maintenance needs and post-Rim Fire activities: frequent or intensive maintenance rotations would occur on linear features, approximately every 5 years, with mechanical and/or prescribed fire.

Fire behavior goals:

- Limit flame lengths to less than 4 feet under 97th percentile or greater weather conditions.
- Limit crown fire potential of any kind (no torching, no active or passive crown fire) to less than 10 percent of treatment feature using 97th percentile weather conditions.

Vegetation density goals (See Figures 5-7 below):

- Conifer and Hardwood/Oak Woodland Dominated Forest Land: open canopy with minimal understory vegetation and wide tree spacing, low density trees per acre, some space between crowns, high crown base height, minimal ladder fuels, and canopy density that will accommodate effective retardant penetration. No snags greater than 30 feet tall.
- Shrublands would be treated to meet fire behavior goals. Shrublands could be treated in a way which develops a mosaic of age classes and species composition. Shrubland mosaics have not proven to be effective fuel treatments in these relatively productive ecosystems. Continuous herbaceous cover develops quickly, and fire spread is sometimes higher in younger age classes. No effective fuel treatment types are known for chaparral, and further research is needed. Mosaics give us places to conduct fire management activities, but do not necessarily provide quality fuel breaks.

Strategic Fire Management *Areas*

Description: polygon-shaped or SPLATs that are often paired with features (linear or fuelbreak-shaped lines), and are placed near WUI and private property. Individually the *areas* are often not delineated on a landscape scale, but cumulatively they amount to strategic placements across the landscape.

Maintenance Needs and post-Rim Fire activities: moderate frequency for maintenance would occur in areas, approximately every 10 years, with mechanical and/or prescribed fire.

Fire Behavior Goals:

- Flame lengths averaging 4 feet, lengths up to 6 feet are acceptable.
- Passive crown fire (torching) is acceptable, but no active or independent crown fire.

Vegetation density goals (See Figures 5-7 below):

- Mosaic of vegetation conditions (age classes, patch sizes) and fire severity is acceptable. Examples: 75% low to moderate and 25% high vegetative severity; or variable density thinning.
- Up to three snags per acre that will not reach a feature or road if fallen.
- Shrublands would be treated to meet fire behavior goals (see information under the Features section above).

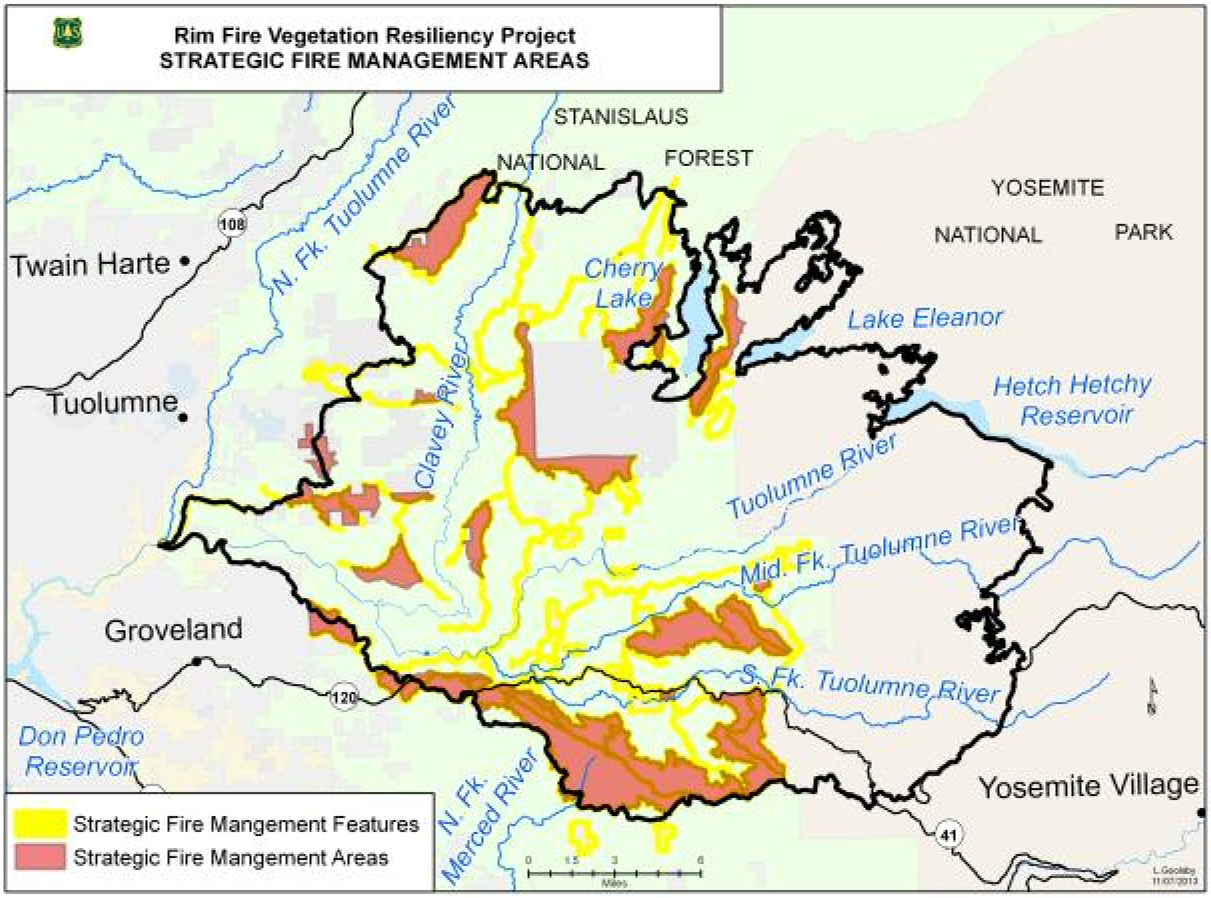

Figure 4. Strategic Fire Management Areas and Features within the Rim Fire perimeter.

Figure 5. Desired conditions for open canopy and light understory fuel in oak woodland/hardwood forests.

Figure 6. Desired conditions for open canopy and light understory fuel in coniferous forest during prescribed burning. Left photo taken in the Lyons Unit of Crandall project area on the Mi-Wok Ranger District; right photo was taken in the Bear Mountain project area on Groveland Ranger District.


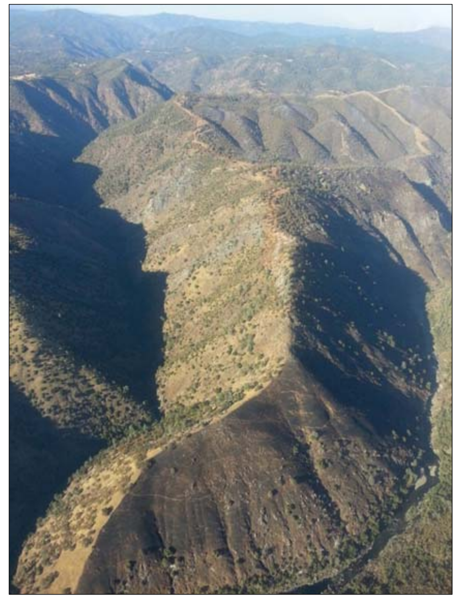

Figure 7. Left photo shows desired conditions of multi-aged shrubland, with heterogeneous age classes resulting from different treatment histories. Right photo shows landscape scale mosaic of shrubland-grassland vegetation on Paper Cabin Ridge after the Rim Fire looking north east. This left photo is an illustration of herbaceous vegetation interspersed with shrubs that can be used for wildfire control and provides burnout opportunities.

Spatial Data and Modeling

Available spatial data and computer modeling were used to help define high risk areas or poor investment areas. This is a model and we recognize that fuel treatments are designed to function under a finite range of conditions. As multiple treatments are accomplished (and tree size increases in forests vegetation types), the effective fire resilience increases. Extreme fire conditions and fire behavior are likely to override treatment design.

Data and spatial analysis categories:

- High and moderate fire severity patterns from 1984 through the 2013 Rim Fire.
- Fire behavior modeling using FlamMap on the pre-Rim fire landscape
- Forest-wide burn probability outputs using the Fire Simulation System (FSIM, Finney and others 2010) analysis by J. Scott (2013) clipped to the Rim Fire perimeter using the same spatial data as FlamMap above.

Cumulative High Fire Severity Analysis

Several fires have burned within the Rim Fire landscape on USFS managed lands multiple times over the past 29 years. Past fires over 1,000 acres have had been mapped for vegetative fire severities (Miller and others 2012) by the Monitoring Trends in Burn Severity program (MTBS) using Landsat-TM satellite. These severity maps provide an opportunity to review and gain an understanding of both individual and cumulative vegetative fire severity and to guide restoration efforts.

Methodology

Fire perimeters and associated vegetative burn severity were obtained for all fires that occurred within the Rim Fire perimeter from 1984-2013. The Composite Burn Index (CBI) was selected for this project because this classification captures changes in the overstory, midstory, and understory post-fire. The CBI is broken down into four classes: unchanged, low, moderate and high severity. These classes have direct correlation to change in canopy cover. This fire severity spatial data was clipped to the areas of the Rim Fire and analysis only considered land within the USFS boundary, including private inholdings.

In order to assess cumulative fire severity, land exposed to two or three fires, as expressed in perimeter data, were combined using a geographic information system (GIS) tool, called raster calculator in ArcGIS 10.0 (ESRI 2013). Similarly, locations found only within two fire perimeters were combined separately. It was important to distinguish between the numbers of fires, since areas that have burned three times may provide a clearer pattern of which areas repeatedly burn at high severity. From these combinations, a rating was calculated based on Table 1 below. The analysis grouped areas that burned at high severity in three fires or burned at high severity in two fires and moderate severity on the third fire (red category). The analysis separately grouped areas with two fires; those that both burned at high severity (yellow category), or where one fire burned at moderate and the other at high severity (blue category).

Table 1. Cumulative CBI ratings for areas that burned two or three times in fires greater than 1,000 acres from 1984 to 2013. See appendix for more detailed table.

Category	**Description**
Areas within three fire perimeters	
Red	The area burned at moderate severity in one fire and burned high in the other two fires, or all three fires burned at high severity.
Areas within two fire perimeters	
Yellow	The area burned at high severity in both fires.
Blue	The area burned at moderate severity in one fire and burned at high severity in a second.

Note: This analysis does not take into account the sequence of fire severity. For example, the sequence did include a high severity area in the first fire, then a moderate severity area in a second fire, and then high severity area in the Rim Fire; or the area could have burned at moderate severity in the first fire, high severity in a second fire, and high severity in the Rim Fire.

Analysis outcomes

Eighteen fires over 1,000 acres were considered for this analysis, including the Rim Fire. All of these fires resulted in varying degrees of fire burn severity under different weather conditions throughout the 1984-2013 period. See Figure 8 for outputs grouped by color categories.

- The red group only considered areas burned at high severity in all three fires or had one of three fires that burned at moderate severity; 1,536 acres *may* be unsuitable for sustainable fire management investments;
- The yellow category only considered areas burned at high severity in two fires; 5,774 acres *may* be unsuitable for fire sensitive management investments;
- The blue category was areas that burned at moderate and high severity in two fires; 14,674 acres *may* be unsuitable for fire sensitive management investments.

The analysis outcomes were compared to a topographic spatial data in ArcGIS. This data represented ridges and mid-slope southwest facing aspects that tend to favor shrub growth and often burn at high severities (Taylor and Skinner 2004, Collins and Stephens 2010). A number of the cumulative high fire severity polygons fell along ridgelines and mid-slopes that were southwest facing (Figure 9). PSW-GTR-220 and 227 suggest managing for vegetation mosaics with strong consideration of topographic patterns (North and others 2009, North 2012).

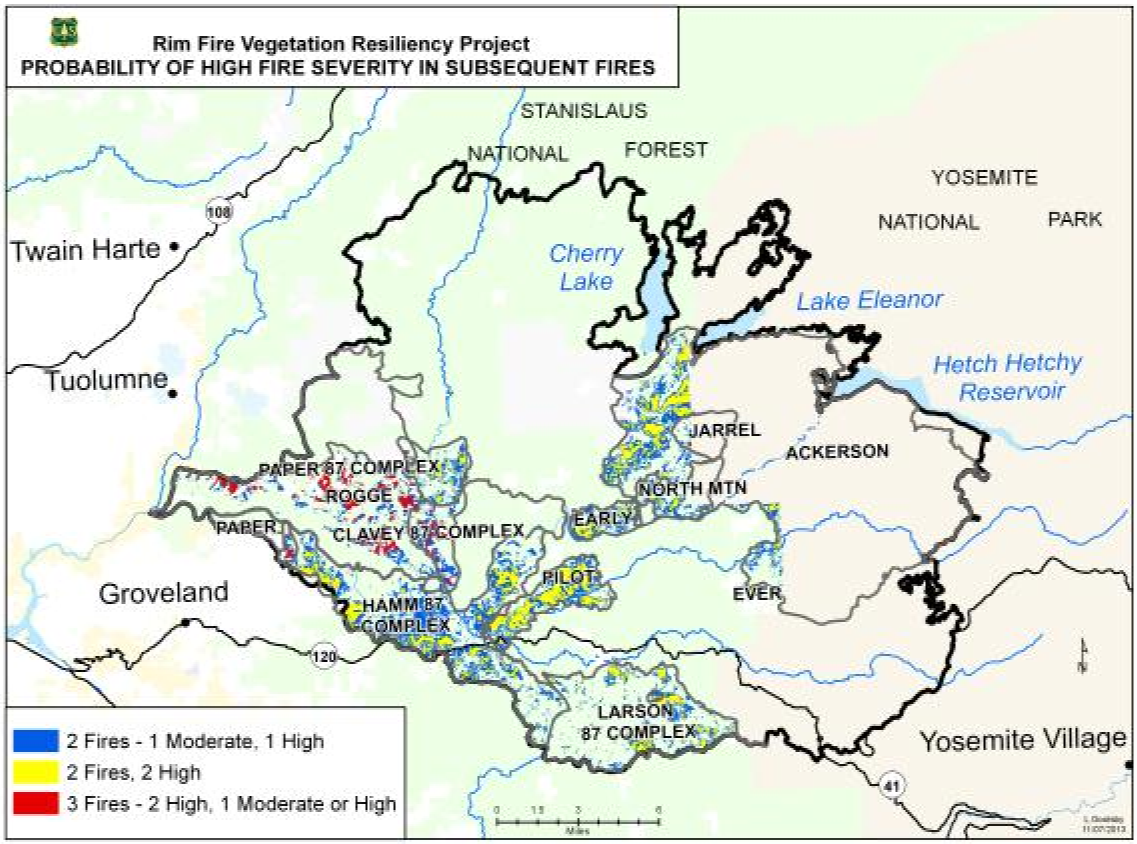

Figure 8. Map of cumulative high and moderate severity (CBI) areas within two to three fire perimeters (1984-2013).

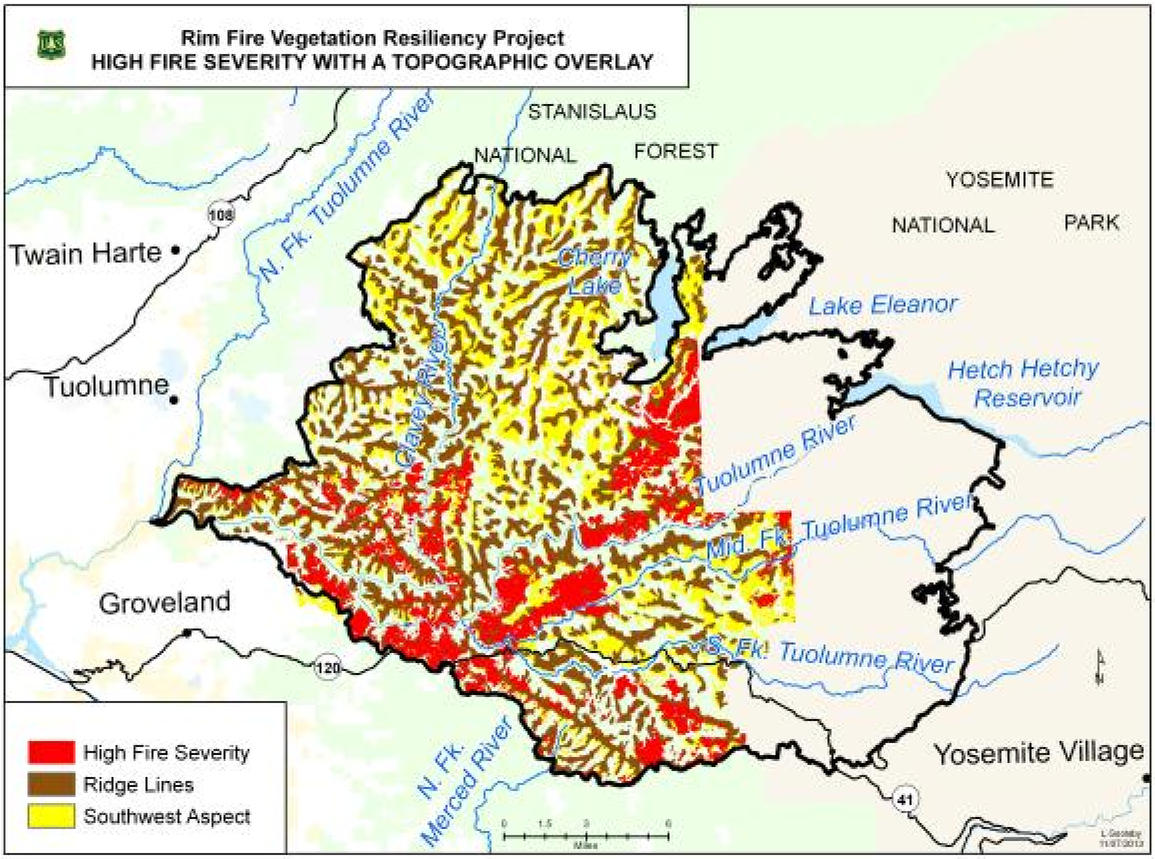

Figure 9. High and moderate fire severity patterns with topographic overlay within the Stanislaus National Forest boundary.

Fire Behavior Modeling

Background

The first few days of the Rim Fire were characterized by 98^{th} percentile weather conditions. 2013 was the second year in a row of below normal precipitation rates and the Central Sierras experienced severe to extreme drought from January 2012 through August 2013 (NOAA 2013; Palmer 1965). The initial days of fire growth occurred during a red flag warning and “significant weather advisory” by the National Weather Service for thunderstorm activity (NWS Aug. 18 and 20, 2013). The STF Forest Plan and SNFPA directs managers to creating strategic fuel treatment placements to use 90^{th} percentile weather. Within the current and changing climate patterns occurring now and predicted for future decades, the range of 90^{th} percentile weather conditions are evolving and affecting fire behavior, local weather patterns, and fire effects. Utilizing weather patterns closer to 97^{th} percentile weather (Table 2) is more appropriate for modeling current and future fire-weather interactions and better addresses the desire to affect fire behavior, fire effects, and utilize fire management opportunities at this time. We realize the common trend, that the two percent of wildfires not easily contained often occur during the 97^{th} percentile or higher weather conditions (and/or have other additional influences like topographic alignment); and we have not been able to plan for, nor implement, enough vegetation change to alter conditions to affect many higher percentile types of fires (i.e. Rim Fire).

Table 2. Weather and fuel moisture parameters for 90th and 97th percentile based on 1997 to 2012 data from Mt. Elizabeth RAWS. *FlamMap modeling used 97th percentile weather.

Weather Parameter	**90th percentile**	**97th percentile***
Wind (mph)	4 to 10, average 7	5 to 12, average 9
Wind direction (degrees)	220	220
Min. to Max. Relative humidity (%)	16 to 35	12 to 25
Min. to Max. Temperature (degrees)	65 to 90	70 to 95
1-hr moisture (%)	3	2
10-hr moisture (%)	4	3
100-hr moisture (%)	5	4
Live woody moisture (%)	90	70
Live herbaceous moisture (%)	90	70
Precipitation (inches)	0	0

FlamMap Modeling

The FlamMap fire behavior model runs on GIS-generated landscape data with a static set of weather and fuel moisture data inputs. FlamMap calculates instantaneous behavior of a fire for each cell on the landscape. Modeling is useful for distinguishing hazardous fuel and topographic combinations. Since FlamMap uses the Rothermel surface spread equation for surface fire spread, crown fire spread, and dead fuel moisture, it has assumptions or limitations:

- All calculations are based on the flaming front, residual combustion is not included.
- The fire is free burning; it is not obstructed by management or natural occurrences.
- The model assumes that the fuels are uniform and continuous within a cell; it does not take into account the natural variability that occurs on the landscape.
- All fire behavior calculations assume that fuel moisture, wind speed and wind direction are constant for the simulation period.
- The fire behavior calculations are performed independently for each cell on the gridded landscape.

The inputs to the model used for this analysis were designed to represent the 97th percentile conditions in the fire area to represent conditions typical of peak fire season. Analysis of the Mt. Elizabeth Remote Area Weather Station (RAWS) data from 1997 to 2012 using the Fire Family Plus was used to determine the appropriate weather parameters (Table 2 above). Prior to running the model, the static wind speed and direction input was corrected for topographic influences using Wind Ninja inside FlamMap. The landscape used in the model to represent the fire area was derived from the LANDFIRE National 2008 data that was updated to reflect changes in this landscape over the past 5 years (e.g., wildfires, vegetation management activities, etc.). The LANDFIRE Total Fuel Change (LFTFC) tool was used by P. Bowden and A. Brough (2013) to calibrate the data. This calibration was completed after input and review by J. Scott and the Sierra, Stanislaus, Sequoia, and Inyo National Forests' fire/fuels experts as part of the Southern Sierra Wildfire Risk Assessment (now in draft form). Changes caused by the Rim Fire were not included because they could have potentially introduced a larger amount of error into the dataset because of the unknown evolution of the vegetation post-fire and the desire to model similar past vegetation that resulted from past management practices. A table in the Appendix shows the percentage of each fuel model (a correlation to vegetation type) in the analysis area. All inputs and data were displayed at 90 meter resolution to match that of the FSim burn probability outputs.

Outputs from FlamMap included flame length and fire type. Flame length can provide a general correlation to many other fire behavior metrics, is indicative of the type of potential suppression action needed (e.g., hand versus mechanical), and is commonly understood and visualized (Figure 10). Fire type (e.g., surface fire, crown fire, etc.) represents the type of fire produced based on the inputs provided to the model. Fire type is described further in Table 3 and illustrated in Figure 11.

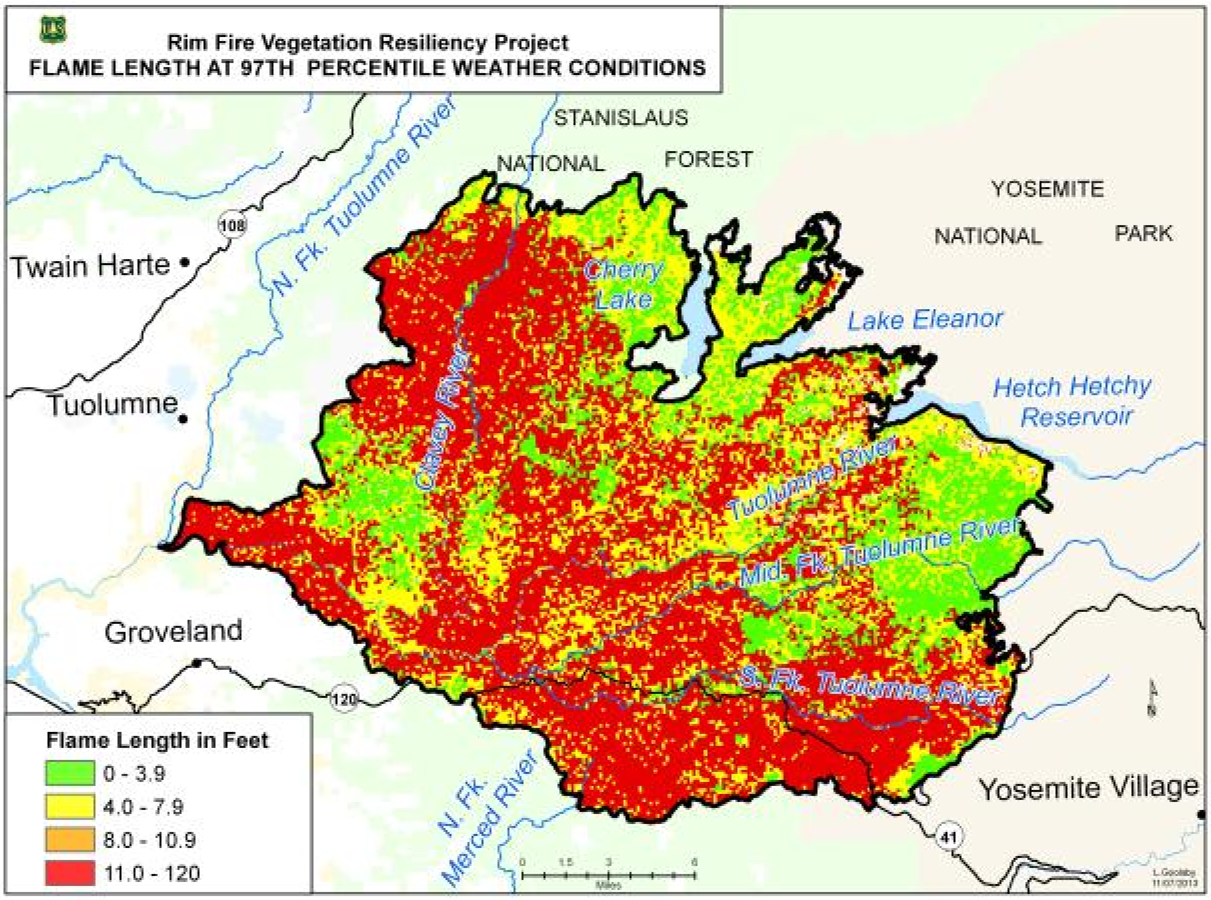

Figure 10. Predicted flame lengths based on 97^{th} percentile weather conditions.

Table 3: FlamMap fire type descriptors shown in Figure 11 below.

Number	Code	Label	Description
1	NF	Non-Forest	Canopy Cover = 0
2	S	Surface (fire)	High Crown Base Height (CBH), Low Canopy Bulk Density (CBD)
3	P1/P2	Passive Crown Fire (Single tree and moderate group torching)	Crown fire (CFB) <25 - 60%
4	P3/C	Active Crown Fire (Significant torching or short duration crown fire dependent on surface fire)	CFB 60-90%, Low CBH, High CBD
5	A	Independent Crown Fire	CFB >90%

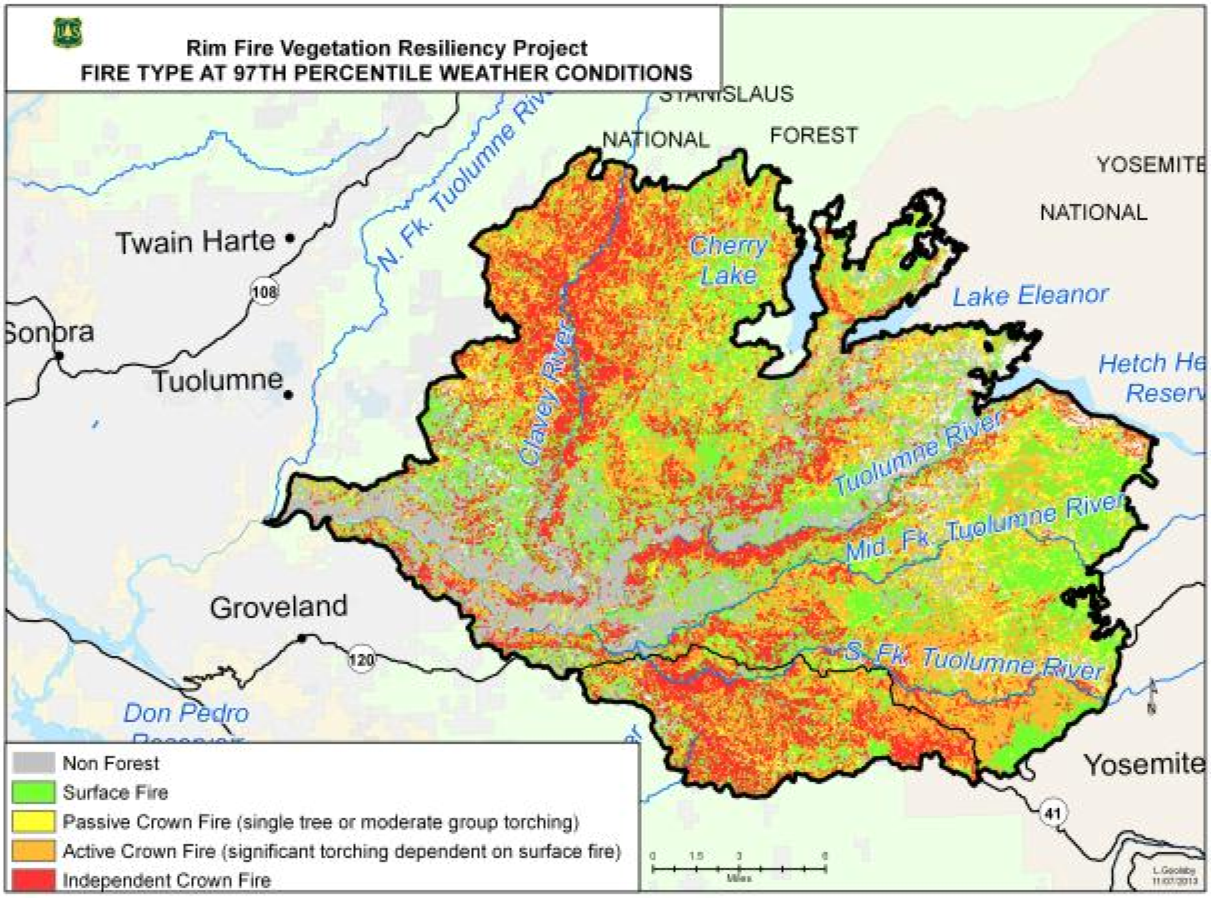

Figure 11. Predicted fire types based on 97th percentile weather conditions.

FSim Modeling

The FSim modeling establishes the probability or likelihood of locations on a landscape to burn given numerous fire starts based on historical fire occurrence, climate and management effort similar to how FSPro models probability for a single fire FSim is a large-fire simulator that was first developed for the Fire Program Analysis (FPA) project. FSim is a comprehensive, stochastic fire ignition, growth, and fire management simulation system. This model pairs a fire growth model with an ignition probability model using simulated weather streams in order to mimic fire ignition and growth for tens of thousands of fire seasons. The results of these simulations are used to estimate annual burn probability for each grid cell across a landscape. In FSim, annual burn probability is estimated by dividing the number of simulated fires that burned each cell by the total number of modeled fire seasons. The FSim modeling demonstrates the probability or likelihood of locations on a landscape to burn given numerous fire starts based on historical fire occurrence, climatology and management effort. FSim is similar to how FSPro models probability for a single fire inside of the online Wildland Fire Decision Support System (WFDSS).

The FSim modeling was completed by J. Scott in cooperation with P. Bowden (USFS R-5 Regional Office) on a spatial landscape estimated for 2012 before the Rim Fire. Both FSim and FlamMap modeling used the same spatial dataset and used 97th percentile weather conditions, but based on different RAWS. FSim burn probabilities were categorized into low, moderate, high, and very high (Figure 12). Additional information about the FSim modeling process, methodology and assumptions are available in the project file and the Appendix.

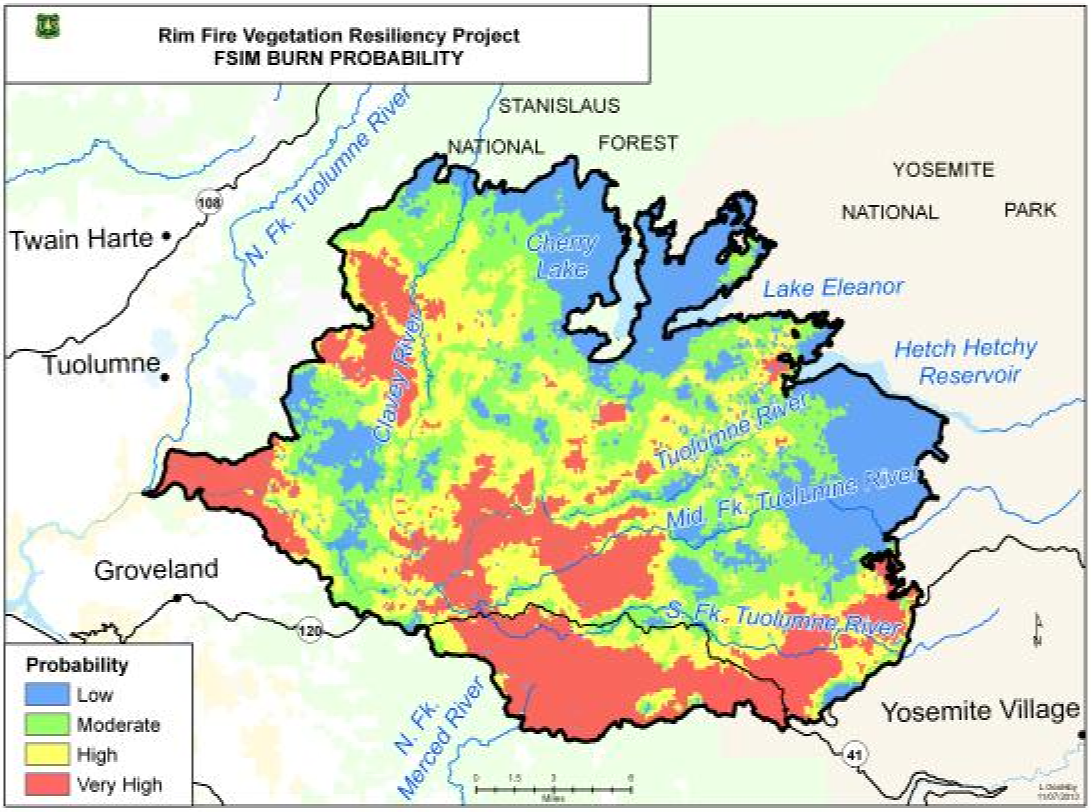

Figure 12. FSim Burn Probability based on 97th percentile weather conditions for multiple RAWS.

Combined Results for Hazard Analysis

The combination of these FlamMap and FSim fire behavior modeling efforts provides a hazard rating analysis where the flame lengths provide the potential fire behavior and the likelihood of the event occurrence (burn probability) is grouped in Table 4, and in Figure 13. Pairing these outputs with associated fire effects to high value investments on the landscape is useful to land management planning, and would be a useful next step. This model provides the opportunity to make land management decisions based on a calculated risk analysis, weighing the importance of a negative outcome with the likelihood of that event occurring; this is a cornerstone of assessing fire risk.

Table 4: FlamMap and FSim inputs to the Relative Fire Hazard Rating.

FlamMap flame lengths in feet					
FSim burn probability		0-3.9 ft (1)	4.0-7.9 ft (2)	8.0-10.9 ft (3)	11.0-120 ft (4)
	Low (1)	Low	Low	Moderate	Moderate
	Moderate (2)	Low	Moderate	Moderate	High
	High (3)	Moderate	Moderate	High	High
	Very High (4)	Moderate	High	High	High

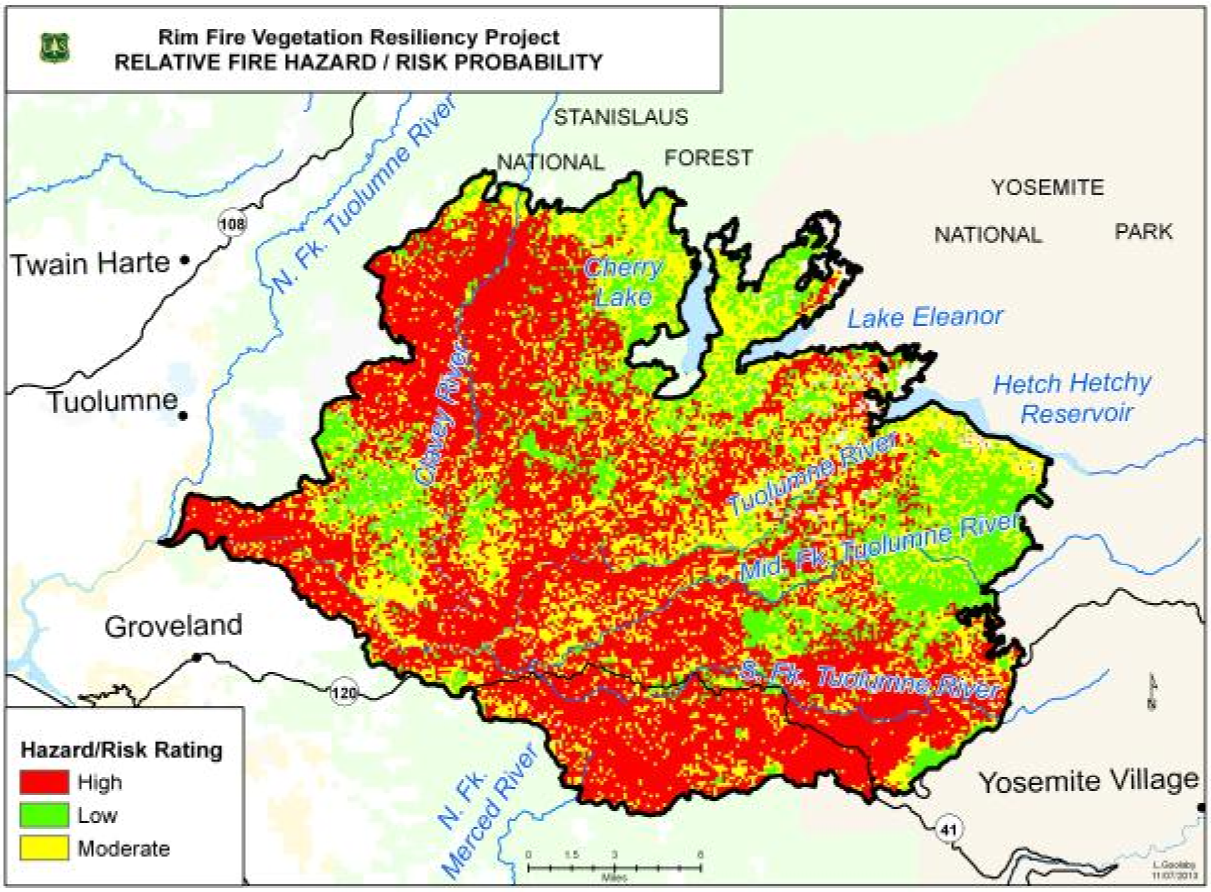

Figure 13. Relative fire hazard rating for the Rim Fire area.

Recommendations to Land Managers

1. Strongly consider the cumulative high/moderate fire severity patterns in terms of:
    - Areas being unsuitable for fire-sensitive management investments (i.e. plantations). Although areas are productive, long term vegetation goals may not be met due to continued frequent or severe fires.
    - High intensity fire and undesirable fire effects are likely.
    - Ideal locations for lower stem densities, and candidates for reintroduction of fire on the landscape.
    - Greater need for active vegetation management with earlier, more frequent and more intense management.
        a. Stands thinned to wider or more variable spacing;
        b. The canopy pruned to raise canopy base heights;
        c. Understory fuels reduced to limit the availability of ladder fuels;
        d. Surface fuels treated to maintain a low level of down woody material, needle cast, leaf litter and other fuels that are the primary component to fire spread.

2. Actively manage areas with a significant dead fuel component. These areas will present a condition for increased fire intensity in the future, resulting in unwanted fire effects and decreased fire suppression efficiency. See the Background/Current Conditions sections for further information on this topic.
    - Remove snags in strategic *areas* and *features* as described in this report
    - Reduce snag densities in areas not identified as strategic fire management areas/features to specific sites. The PSW Science Synthesis suggests targeting post-fire treatments to particular sites where the expected benefits exceed the costs of interventions and to address scrutiny about cost effectiveness and undesirable ecological effects. Post-fire landscapes offer opportunity to realign ecosystem structure, function, and/or composition with expected future climate and fire regimes.
    - RMRS_GTR_310 emphasizes that mechanical treatments may be necessary to initiate suitable composition and structure before reintroducing fire.

3. Use topographic landscape features as a guide to planting locations and densities. Sites that are prone to frequent and moderate to high fire behavior include:
        a. low elevation,
        b. southerly aspect or ridgelines, or
        c. steep slopes (>50%)

    The combination of any of these variables increases fire behavior considerably. Reforestation efforts should focus on areas with topographic characteristics likely to experience low to moderate severity fire. Incorporate these patterns to develop forest structure less capable of sustaining high fire severity.

4. Use the identified priority fire management areas similar to a pre-planning fire management map tool to inform wildfire management operational decision making.
        a. Input and update these as necessary in WFDSS.

b. Meet annually to identify areas where wildfire management can consider a wide range of objectives and where suppression tactics are most needed.

5. Consider the likelihood of fire occurring on the landscape with as much weight as potential fire behavior.

6. Increase the range of acceptable mortality and scorch and biomass removal/consumption in vegetation prescriptions when managing fire, implementing fuel treatments, and maintaining fuel treatments in order to build a fire resilient landscape. Evaluate and incorporate lessons learned from fire effects in subsequent treatments.

7. Evaluate the landscape outside the Rim Fire where the same principles described in this report could be used to retain the existing resource values and create a landscape with increased resiliency to fire. Renew/design the Forest-wide treatment prioritization model for project maintenance and future project identification.

8. Incorporate related research and modeling efforts into ongoing and upcoming planning efforts (i.e. Rim Fire Fuel Treatment Effectiveness Monitoring, USFS PSW Science Synthesis, and the USFS Southern Sierra Wildfire Risk Assessment).

Goals and Objectives Aiming Toward Resiliency

1. Fuel treatments must be continuously maintained to be effective.
2. Do not plant or create overstocked, homogenous forests.
3. Manage areas that are already overstocked.
4. Manage for heterogeneous vegetation (gaps, clumps, age/variable sizes, and species).
5. Prepare landscape-scale vegetation (i.e. restoration efforts) to enable the reintroduction of fire as an ecosystem process. A risk/opportunity assessment similar to the current Southern Sierra Wildfire Risk Assessment can be used.
6. Reduce negative fire effects/severity on natural resources, rather than focusing on fire size.
7. Manage wildfires that are candidates for multiple objectives, not just in areas adjacent to the wilderness and Yosemite.
8. Regulate fire-induced effects across the landscape utilizing wildfires over time, as appropriate.
9. Maintain strategies that focus on prescribed fire to reduce the vulnerability of the landscape to large, high severity fires.
10. Expand opportunities to enable the increased application of fire on the landscape which would enable larger burns to be completed (i.e. staffing levels or air quality constraints).

References

Agee, J.K., 1993. Fire Ecology of the Pacific Northwest. Island Press, Washington, D.C.

Agee, J.K., C.N. Skinner. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management. 211: 83–96.

Barbour, M., E. Kelley, P. Maloney, D. Rizzo, E. Royce, J. Fites-Kaufmann. 2002. Present and past old-growth forest of the Lake Tahoe Basin, Sierra Nevada. U.S. Journal of Vegetation Science. 13: 461–472.

Barrett, S.; D. Havlina, J. Jones, W. Hann, C. Frame, D. Hamilton, K. Schon, T. Demeo, L. Hutter, J. Menakis. 2010. Interagency Fire Regime Condition Class Guidebook. Version 3.0 [Homepage of the Interagency Fire Regime Condition Class website, USDA Forest Service, US Department of the Interior, and The Nature Conservancy]. Available online: http://www.frcc.gov/

Beaty, R.M., A.H. Taylor. 2008. Fire history and the structure and dynamics of a mixed conifer forest landscape in the northern Sierra Nevada, Lake Tahoe Basin, California, USA. Forest Ecology and Management. 255(3-4): 707-719.

Bond, W.J., B.P. van Wilgen. 1996. Fire and plants. London: Chapman and Hall. 263 p.

Bonnicksen, T.M.; Stone, E.C. 1982. Reconstruction of a presettlement giant sequoia-mixed conifer forest community using the aggregation approach. Ecology. 63: 1134–1148.

Bowden, P., A. Brough, J. Scott, 2013. Related calibrations to the LANDFIRE spatial data inputs for FSim modeling for the SSWRA.

Brown, J.K., J.K. Smith. 2000. Wildland Fire in Ecosystems, Effects of Fire on Flora. US For. Serv. Gen. Tech. Rep. GTR-RMRS-42(2).

Cocking, M.I., J.M. Varner, R.L. Sherriff. 2012. California black oak responses to fire severity and native conifer encroachment in the Klamath Mountains. Forest Ecology and Management. 270: 25-34.

Collaborative Forest Landscape Restoration Program (CFLRP). Available online: http://www.fs.fed.us/restoration/CFLRP/index.shtml/index.shtml

Collins, B. M., S. L. Stephens. 2010. Stand-replacing patches with a 'mixed severity' fire regime: quantitative characterization using recent fires in a long-established natural fire area. Landscape Ecology 25:927-939.

Collins, B. M., H.A. Kramer, K. Menning, C. Dillingham, D. Saah, P.A. Stine, S.L. Stephens. 2013. Modeling hazardous fire potential within a completed fuel treatment network in the northern Sierra Nevada. Forest Ecology and Management 310, 156-166.

Covington, W.W., P.Z. Fule, W.W. Moore, S.C. Hart, T.E. Kolb, J.N. Mast, S.S. Sackett, M.R. Wagner. 1997. Restoring ecosystem health in ponderosa pine forests of the Southwest. Journal of Forestry. 95: 23–29.

Crotteau, J., J.M. Varner, M. Ritchie. 2013. Post-fire regeneration across a fire severity gradient in the southern Cascades. Forest Ecology and Management. 287: 103-112.

ESRI. 2013. ArcGIS Desktop: Release 10. Environmental Systems Research Institute, Redlands, CA, USA.

Finney, M.A. 2006. An overview of FlamMap fire modeling capabilities. In: Fuels management – how to measure success: conference proceedings. 2006 March 28-30; Portland, Oregon. Proceedings RMRS-P-41. Fort Collins CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 213-220.

Finney, M., and others. 2011. Fire Simulation System (FSim).

Finney, M., C.W. McHugh, I. Grenfell, K. L. Riley. 2010. Continental-scale simulation of burn probabilities, flame lengths, and fire size distribution for the United States. From the VI International Conference on Forest Fire Research D. X. Viegas (Ed.), 2010. Available online: http://www.fs.fed.us/rm/pubs_other/rmrs_2010_finney_m002.pdf

Kane, V. R, J.A. Lutz, S.L. Roberts, D.F. Smith, R.J. McGaughey, N.A. Povak, M.L. Brooks. 2013. Landscape-scale effects of fire severity on mixed-conifer and red fir forest structure in Yosemite National Park. Forest Ecology and Management. 287: 17-31.

Kobziar, L.N., J.R. McBride, S.L. Stephens. 2009. The efficacy of fire and fuels reduction treatments in a Sierra Nevada pine plantation. International Journal of Wildland Fire. 18: 791–801.

Long, J., C. Skinner, M. North, P. Winter, B. Zielinski, C. Hunsaker, B. Collins, J. Keane, F. Lake, J. Wright, E. Moghaddas, A. Jardine, K. Hubbert, K. Pope, A. Bytnerowicz, M. Fenn, and M. Busse (USDA Forest Service PSW Research Station), S. Charnley and T. Patterson (USDA FS PNW Research Station), L. Quinn-Davidson (UC Cooperative Extension), H. Safford (USDA FS PSW Region Ecology Program) were chapter authors and synthesis team members. 2013. Science Synthesis to Promote Resilience of Social-ecological Systems in the Sierra Nevada and Southern Cascades. Pacific Southwest Research Station, Final draft (1/9/13) is available at: http://www.fs.fed.us/psw/publications/reports/psw_sciencesynthesis2013/psw_sciencesynthesis2013.pdf

Lydersen, J.M., M.P. North, E.E. Knapp, B.M. Collins. 2013. Quantifying spatial patterns of tree groups and gaps in mixed-conifer forests: reference conditions and long-term changes following fire suppression and logging. Forest Ecology and Management 304 (2013) 370–382.

McCaffrey, S. 2008. A homeowner view of thinning methods for fire hazard reduction: More positive than many think. In: Narog, M.G., ed. Proceedings of the 2002 Fire Conference: managing fire and fuels in the remaining wildlands and open spaces of the Southwestern United States. PSW-GTR-189. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 15-22.

Meyer, M., M. North, A. Gray, H. Zald. 2007. Influence of soil thickness on stand characteristics in a Sierra Nevada mixed-conifer forest. Plant and Soil. 294: 113–123.

Miller, J. D., C. N. Skinner, H. D. Safford, E. E. Knapp, and C. M. Ramirez. 2012. Trends and causes of severity, size, and number of fires in northwestern California, USA. Ecological Applications 22:184-203.

Minnich, R.A., M.G. Barbour, J.H. Burk, R.F. Fernau. 1995. Sixty years of change in Californian conifer forests of the San Bernardino Mountains. Conservation Biology. 9: 902–914.
Nagel, T.A., A.H. Taylor. 2005. Fire and persistence of montane chaparral in mixed conifer forest landscapes in the northern Sierra Nevada, Lake Tahoe Basin, California, USA 1. Sierra. 132(3): 442-457.

National Oceanic and Atmospheric Administration. 2013. National Climate Data Center, Palmer Hydrological Drought Index, October United States Release. NOAA, Denver, CO. http://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers.php (Accessed Nov. 2013).

National Weather Service (NWS), Sacramento and San Joaquin Valley, National Oceanic and Atmospheric Administration. Red Flag Warning and Special Weather Statements for Aug. 18 and 20, 2013. Website: http://www.wrh.noaa.gov/sto/

North, M. 2006. Restoring forest health: fire and thinning effects on mixed-conifer forests. Science Perspectives 7. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 6 p.

North, M., J. Innes, H. Zald. 2007. Comparison of thinning and prescribed fire restoration treatments to Sierran mixed-conifer historic conditions. Canadian Journal of Forest Research. 37: 331–342.

North, M., P. Stine, K. O'Hara, W. Zielinski, S. Stephens. 2009. Gen. Tech. Rep. PSW-GTR-220 (Second printing, with addendum). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 49p. Available online:
http://www.fs.fed.us/psw/publications/documents/psw_gtr220/

North, M., B. M. Collins, S. Stephens. 2012. Using Fire to Increase the Scale, Benefits, and Future Maintenance of Fuels Treatments. Journal of Forestry 110:392–401.

North, M., ed. 2012. Managing Sierra Nevada forests. Gen. Tech. Rep. PSW-GTR-237. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 184 p. Available online: http://www.fs.fed.us/psw/publications/documents/psw_gtr237/psw_gtr237.pdf

Oliver, C.D., B.C. Larson. 1996. Forest stand dynamics. Updated edition. New York: NY. John Wiley and Sons, Inc. 520 p.

Palmer, W.C. 1965. Meteorological drought. *Research Paper No. 45.* U.S. Weather Bureau. NOAA Library and Information Services Division, Washington, D.C. 20852.

Piirto, D.D., R. Rogers. 2002. An ecological basis for managing giant sequoia ecosystems. Environmental Management. 30: 110–128.

Rapid Assessment of Vegetation Condition after Wildfire (RAVG) process. 2013. Available online: http://www.fs.fed.us/postfirevegcondition/

Reynolds, R. T., A.J. Sánchez Meador, J.A. Youtz, T. Nicolet, M.S. Matonis, P.L Jackson, D.G. DeLorenzo, A.D. Graves. 2013. Restoring composition and structure in Southwestern frequent-fire forests: A science-based framework for improving ecosystem resiliency. Gen. Tech. Rep. RMRS-GTR-310. Fort Collins, CO, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 76 p. Available online: http://www.fs.fed.us/rm/pubs/rmrs_gtr310.html

Ryan, R.L., E. Hamin. 2006. Engaging communities in post-fire restoration: Forest treatments and community-agency relations after the Cerro Grande Fire. In McCaffrey, S. (ed.), In: The public and wildland fire management: Social science findings for managers. Gen. Tech. Rep. NRS-1. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 87-96.

Ryan, R.L., E. Hamin. 2008. Wildfires, communities, and agencies: Stakeholders' perceptions of postfire forest restoration and rehabilitation. Journal of Forestry. 106 (7): 370-379.

Ryan, R.L., E. Hamin. 2009. Wildland-urban interface communities' response to post-fire salvage logging. Western Journal of Applied Forestry. 24 (1): 36-41.

Safford, H.D., K. van de Water, D. Schmidt. 2011. California Fire Return Interval Departure (FRID) map, 2010 version. USDA Forest Service, Pacific Southwest Region and the Nature Conservancy-California. Available online: http://www.fs.fed.us/r5/rsl/clearinghouse/r5gis/frid/ or http://fsweb.r5.fs.fed.us/program/ecology/documents/pubs/CaliforniaFRID-GISMetadata111011.pdf

Schwilk, D.W., J.E. Keeley, E.E. Knapp, J. McIver, J.D. Bailey, C.J. Fettig, C.E. Fiedler, R.J. Harrod, J.J. Moghaddas, K.W. Outcalt, C.N. Skinner, S.L. Stephens, T.A. Waldrop, D.A. Yaussy, A. Youngblood. 2009. The national Fire and Fire Surrogate study: effects of alternative fuel reduction methods on forest vegetation structure and fuels. Ecological Applications. 19: 285–304.

Scott, J. 2013. Draft internal USFS fire behavior and burn probability outputs from FSIM-based analysis for the Southern Sierra Wildfire Risk Assessment (SSWRA).

Stephens, S.L., J.J. Moghaddas. 2005. Silvicultural and reserve impacts on potential fire behavior and forest conservation: 25 years of experience from Sierra Nevada mixed conifer forests. Biological Conservation. 25: 369–379.

Stephens, S.L., D. Fry, E. Franco-Vizcaíno. 2008. Wildfire and forests in northwestern Mexico: the United States wishes it had similar fire problems. Ecology and Society. http://www.ecologyandsociety.org/vol13/iss2/art10/

Stephenson, N.L. 1999. Reference conditions for giant sequoia forest restoration: structure, process, and precision. Ecological Applications. 9: 1253–1265.

Stephens, S.L., J.J. Moghaddas, C. Ediminster, C.E. Fiedler, S. Hasse, M. Harrington, J.E. Keeley, J.D. McIver, K. Metlen, C.N. Skinner, A. Youngblood. 2009. Fire and treatment effects on vegetation structure, fuels, and potential fire severity in six western U.S. forests. Ecological Applications. 19: 305–320.

Stratton, R.D. 2009. Guidebook on LANDFIRE fuels data acquisition, critique, modification, maintenance, LANDFIRE www.landfire.gov (also known as Landscape Fire and model calibration). General Technical Report RMRS-GTR-220. Fort Collins, CO: U.S. Resource Management Planning Tools. Sponsored by the United States Department of the Interior (DOI) and the United States, Department of Agriculture, Forest Service., Rocky Mountain Research Station. LANDFIRE Data Calibration - 0.12 version of the LFTFC (LANDFIRE Total Fuel Change) Tool for ArcGIS 10. LFTFC Info available online: http://www.frames.gov/partner-sites/niftt/tools/niftt-current-resources/

Skinner, C.N., A.H. Taylor. 2006. Southern Cascade bioregion. In Sugihara, N.G.; van Wagtendonk, J.W.; Fites-Kaufman, J.; Shaffer, K.E.; Thode, A.E. (eds.), In: Fire in California's ecosystems. Berkeley: University of California Press: 195-224.

Suigihara, N., J. van Wagtendonk, K.E. Shaffer, J. Fites-Kaufman, A. Thode (Editors), J. K. Agee (Foreword). 2006. Fire in California’s Ecosystems. University of California Press, Berkeley and Los Angeles, CA.

Taylor, A. 2004. Identifying forest reference conditions on early cut-over lands, Lake Tahoe Basin, USA. Ecological Applications. 14: 1903–1920.

Taylor, A. H., C. N. Skinner. 2004. Spatial patterns and controls on historical fire regimes and forest structure in the Klamath Mountains. Ecological Applications 13:704-719.

US Forest Service. 2013. Fire Effects Information System (FEIS). Available online: http://www.fs.fed.us/database/feis/index.html

Appendix

Table A1. Cumulative Composite Burn Index (CBI) for areas within three and two historic fire perimeters (1984-2013 and fires greater than 1,000 acres). Colors show which ratings were grouped in Figure 7.

Combined CBI	Description
Areas within three fire perimeters	
3	The area remained unburned in all 3 fires.
4	The area remained unburned except in one fire where it burned at low severity.
5	The area remained unburned except in one fire where it burned at moderate severity or the area burned at low severity in 2 fires and was unburned in the third fire.
6	The area was unburned in one fire, burned low in a second fire and moderate in a third fire.
7	The area was unburned in one fire, burned low in a second fire and high in a third fire.
8	The area was unburned in one fire, burned moderate in a second fire and high in a third fire.
9	The area burned at low severity in one fire, burned moderate in a second fire and high in a third fire.
10	The area burned at low severity in one fire and burned high in the other two fires.
11	The area burned at moderate severity in one fire and burned high in the other two fires.
12	The area burned at high severity in all three fires.
Areas within 2 fire perimeters	
2	The area remained unburned in both fires.
3	The area was unburned in one fire and burned at low severity in a second.
4	The area was unburned in one fire and burned at moderate severity in a second.
5	The area burned at low severity in one fire and burned at moderate severity in a second.
6	The area burned at low severity in one fire and burned at high severity in a second.
7	The area burned at moderate severity in one fire and burned at high severity in a second.
8	The area burned at high severity in both fires.

Table A2: Fuel Models Represented in the Landscape (by percentage) for the Rim Fire and adjacent area.

Fuel Model	Description	Percentage	
91, 98, 99	Non-burnable	7.9	(NB) 7.9
101	Short, Sparse Dry Climate Grass	0.3	(GR) 7.8
102	Low Load, Dry Climate Grass	7.5	
121	Low Load, Dry Climate Grass-Shrub	1.4	(GS) 13.9
122	Moderate Load, Dry Climate Grass-Shrub	12.5	
141	Low Load, Dry Climate Shrub	<0.1	(SH) 7.6
142	Moderate Load Dry Climate Shrub	1.0	
143	Moderate Load, Humid Climate Shrub	<0.1	
145	High Load, Dry Climate Shrub	3.0	
147	Very High Load, Dry Climate Shrub	3.6	
161	Low Load, Dry Climate Timber-Grass-Shrub	1.4	(TU) 24.4
162	Moderate Load, Humid Climate Timber-Shrub	<0.1	
165	Very High Load, Dry Climate Timber-Shrub	23.0	
181	Low Load, Compact Conifer Litter	<0.1	(TL) 38.3
182	Low Load Broadleaf Litter	0.3	
183	Moderate Load Conifer Litter	4.1	
184	Small Downed Logs	6.7	
185	High Load Conifer Litter	0.5	
186	Moderate Load Broadleaf Litter	18.2	
187	Large Downed Logs	7.6	
188	Long Needle Litter	0.6	
189	Very High Load Broadleaf Litter	0.3	
202	Moderate Load Activity Fuel or Low Load Blowdown	<0.1	<0.1

Fire Simulation System (FSim)

FSim, a large-fire simulator, was first developed for of the Fire Program Analysis (FPA) project (http://fpa.nifc.gov/). FSim is a comprehensive, stochastic fire ignition, growth, and suppression simulation system that pairs a fire growth model (Finney 1998, Finney 2002) and a model of ignition probability with simulated weather streams in order to simulate fire ignition and growth for tens of thousands of fire seasons. The results of these simulations are used to estimate annual burn probability (BP) for each grid cell across a landscape. In FSim, annual BP is estimated by dividing the number of simulated fires that burned each pixel by the total number of simulated fire seasons. Joe Scott and others used FSim (Finney and others 2011) to determine geospatial burn probability across the static circa 2012 landscape for the Southern Sierra Wildfire Risk Assessment.

FSim produces an estimate of the circa 2012 burn probability for the Southern Sierra Wildfire Risk Assessment, but not estimates of burn probability for future fire seasons. In FSim, the fire modeling landscape (LCP) remains unchanged between fire simulations and fire seasons; there is no attempt to simulate how simulated fires may affect future fire growth. FSim is parameterized and calibrated based on past weather and fire occurrence, typically going back about 20 years. However, the last decade has been dryer than the previous decade, therefore going back 20 years for fire history may undervalue the intensity and probability compared to what is currently being experienced. Research efforts are now underway to simulate fire likelihood under a changing climate with FSim, but those methods are not yet available for use on this project. FSim is designed primarily to illustrate how fire likelihood is distributed spatially across a landscape in relation to ignition density and fire growth potential across the landscape. The absolute level of likelihood is assumed to be roughly equal to that indicated by past fire occurrence. If that is not the case, FSim's results could under- or over-estimate actual BP. Remembering all of that you can think of BP in a static term of “recurrence chance” (RC) in years by dividing 1 by the BP. So the high RC in the Rim fire was 1/0.0244 = 41 recurrence chance in years. For the Southern Sierra Wildfire Risk Assessment, Joe Scott used the 1 minute wind speed of 17mph. See page 54 of Fire Management Today (vol. 64) for details. Also see Finney and others (2010) for information.